

# **Sediment Acoustics**

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## **LONG-TERM GOAL**

The long-term goal of my work in sediment acoustics is to develop a practical as well as physically meaningful model to describe geoacoustic wave propagation in marine sediments on the basis of a set of primitive physical variables.

## **OBJECTIVES**

The principal scientific objective of my work has been to develop a mathematical model that is able to predict wave velocity and attenuation in the sediments found near the seafloor. Specifically, the model has been designed to accept as input parameters certain fundamental primitive variables, such as grain size, porosity, grain density and gas content that are directly related to the geological processes producing the wide range of sediments that are encountered in the world's oceans. A number of auxiliary technological objectives have also arisen in the course of our work related to remote sensing and in-situ measurement of sediment geoacoustic properties. One of these objectives has been to develop a set of tools that allow the measurement of velocity and attenuation as well as certain related geotechnical variables such as shear strength in the sediment column. These measurements provide the "ground truth" for assessing the validity and usefulness of the basic geoacoustic model.

## **APPROACH**

My approach has been to develop a theoretical geoacoustic model based on the classical Biot theory for porous, fluid-filled media. The model reflects the influence of variables such as porosity and overburden pressure and includes several kinds of intrinsic attenuation that are important in different kinds of ocean sediment. We have performed extensive field and laboratory experiments aimed at determining appropriate input parameters as well as checking the validity of the model predictions. Much of our earlier work is described in the monograph "Sediment Acoustics" (Stoll, 1989). More recent progress, especially the results of extensive field work, has been described in a series of technical papers and is being incorporated into several new chapters in a second edition of the monograph to be published in the near future. Over the past several years we have participated in a number of field experiments in cooperation with other investigators such as T. Akal at SACLANT Undersea Research Center in LaSpezia, Italy and M. Richardson at the Naval Research Laboratory, Stennis Space Center. During this work several new testing techniques were developed to measure in-situ properties of the sediments immediately beneath the seafloor including shear wave velocity and attenuation for both vertically and horizontally polarized wave motion, and undrained shear strength based on quasistatic cone penetration tests. In addition, sediment cores taken at many sites were analyzed to obtain porosity, grain size distribution and other fundamental properties, the objective being to establish the ground truth at each test location and develop correlations between such quantities as in-situ shear wave velocity, undrained shear strength and porosity.

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In addition to the field work mentioned above, a new series of laboratory experiments were begun with the purpose of studying the dispersion that occurs during p-wave propagation in granular sediments as one moves from the “low frequency” regime to the “high frequency” range that is currently of considerable interest. The purpose of this work is to help in the evaluation of some of the new propagation models that are being proposed to explain the penetration of acoustic energy into the seafloor at low grazing angles observed in recent experiments. Some of these new models that are based largely on high frequency data, and in some cases idealized scattering models, do not properly account for the dispersion that would normally be expected in going from low to high frequencies and therefore may be questionable for applications in the general case.

## **WORK COMPLETED**

During the past year our research team, which includes R. Stoll and I. Bitte from Lamont-Doherty Observatory and R. Flood from the Marine Research Lab, SUNY, Stony Brook, carried out two field experiments, one in New York Harbor and the other in the Gulf of Mexico near Ft. Walton Beach, Florida. These experiments, which are part of the ONR High Frequency Acoustics DRI, were aimed at establishing certain lower frequency bounds on velocity dispersion that occurs in the coarser granular sediments and is predicted by the Biot theory. In preparing for these experiments, our source and linear bottom array of receivers were modified to obtain higher resolution and permit velocity measurements in the sediment immediately beneath the sea floor. In addition Stoll participated in several planning meetings for the SAX99 experiments being carried out in the Gulf.

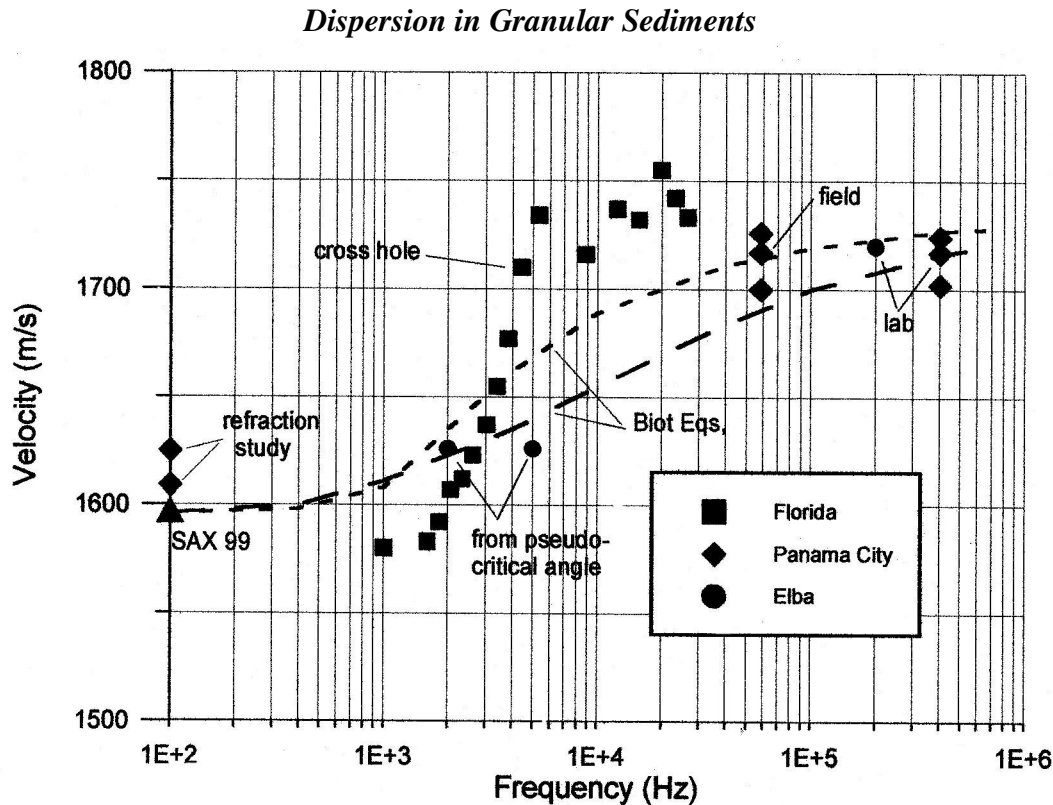
In the lab, we have been modifying test equipment to allow more extensive acoustic testing of granular sediments in the low frequency range.

## **RESULTS**

Analysis of our field data, which is only partially complete at this time, shows that there is pronounced velocity dispersion that occurs in uniform, unconsolidated sands over an intermediate frequency range (typically about 1kHz to 10 kHz, but shifting upwards as permeability decreases). This dispersion, which is one of the most striking predictions of the Biot theory, has important implications when interpreting bottom-penetrating sonar records (Maguer et al, 1999) as well as when choosing attenuation values for geoacoustic modeling purposes. Our results suggest that the historical method of cataloging attenuation as a single value valid at 1kHz and then assuming that the attenuation varies as (or nearly as) the first power of frequency can lead to poor estimates when extrapolating to a different frequency range. Moreover, these results also demonstrate that a linear viscoelastic model, based on an assumed relaxation function that leads to attenuation varying as the first power of frequency, is not adequate for describing the response of marine sediments such as unconsolidated sand.

Some recent experimental results that illustrate the extent and importance of the velocity dispersion are shown in the figure below. The data points labeled Florida are based on work by Turgut and Yamamoto (1990) wherein direct measurements of velocity between a buried source and receivers were made in a beach sand. High frequency data from Panama City is based on field measurements with probes at 58 kHz and lab measurements made on cores at 400 kHz as reported by Richardson and Briggs (1996) whereas the low frequency points were derived from refraction studies done by Stoll as a part of the CBBL program. The lower frequency points labeled Elba are based on critical angle

measurements made by Maguer et al (1999) in clean sand near the Isle of Elba whereas the high frequency point was based on shipboard measurements on cores of this sediment. The Biot dispersion curves shown in the figure are based on input parameters given in their paper. Finally the single point labeled SAX99 is based on a preliminary analysis of refraction data from recent tests carried out in the ONR experiments located near Ft. Walton Beach Florida.



## IMPACT/APPLICATION

While our primary interest has been to model geoaoustic properties of the sediment, a number of tools developed for our field work have direct applications to other areas of interest to the Navy such as mine counter-measures. As an example, the penetration resistance measured by several different types of probe we have developed is directly related to the bearing capacity of the sediment which is of prime importance in studies of mine burial in the seafloor. These probes have been used to map critical areas in two recent NATO exercises aimed at 'Rapid Environmental Assessment'.

## TRANSITIONS

We have prepared an XBP (expendable bottom penetrometer) evaluation package for the Naval Oceanographic Office composed of software, an electronics interface board and a users manual for use on board NAVO ships. In addition, quasistatic cone penetrometers have been built for SACLANT Undersea Research Center and for the Naval Research Lab, SSC and a beach penetrometer was also built for NRL.

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